STRUCTURE AND EVOLUTION OF THE SATURN'S SUBNEBULA – IMPLICATIONS FOR THE FORMATION OF TITAN. Y. Alibert[1] and O. Mousis[2], [1]Physikalisches Institut, Universitaet Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland (Yann.Alibert@phim.unibe.ch); [2]Observatoire de Besançon, CNRS-UMR 6091, 41 bis Avenue de l'Observatoire, BP 1615 Besançon, France.

Introduction: Recent models of giant planets formation include migration in a solar nebula whose evolution is ruled through viscosity and photoevaporation [1]. These models allow to form planets in a timescale well within observed disks lifetimes. Here, we utilize some results presented on Saturn formation [2] to calculate the structure of its surrounding subnebula, in a way consistent with the formation process of the planet, by using a two-dimensional evolutionary turbulent alpha-model. In this context, the evolution of the subnebula is ruled by the last phase of Saturn's formation. We also discuss the implications for the formation of Titan in the Saturnian subnebula.

Saturn's formation: The formation process of Saturn can be divided in two parts [2]: in the first part, the gas accretion rate onto the planet is lower than what can be provided by the disk and is controlled by the planet. The total radius of Saturn equals its Hill's radius and no subnebula can exist. During the second part, a gap is opened around the planet and the accretion rate of gas is then governed by the disk itself. The accretion of gas is no more symetric, and proceeds through streamers that collide [3]. A circumplanetary disk emerges from the contracting atmosphere [4], and the resulting subnebula is fed by gas and gas-coupled solids accreted from the nebula.

Evolution of the subnebula: The evolution of the subnebula proceeds in two phases. During the first phase, the solar nebula is still present, and the subnebula is fed through its outer edge. During the second phase, the nebula has disappeared and the subnebula evolves only due to the accretion of its material onto the planet. During this period, the subnebula also expands, due to angular momentum conservation.

The structure of the subnebula is calculated by solving the diffusion equation, the mean viscosity being calculated with the help of the vertical structure of the subdisk [1]. The outer boundary condition used to solve the diffusion equation varies, depending upon the presence of the protoplanetary disk. During the first phase, the subnebula is fed from its outer radius by gas originating from the disk. We impose the accretion rate of gas at the outer radius of subnebula, by using the results of the Saturn formation model [2]: the accretion rate from the nebula to the subnebula is the one calculated during the late phase of Saturn's formation. Based on hydrodynamical simulations [3], the outer radius of the subnebula is fixed at 1/5 Hill's radius of Saturn (around 200 R_{Sat} - radius of Saturn). After the disk has vanished, the outer radius of the disk is allowed to freely expand. The surface density is fixed to 0 at 1050 R_{Sat}, corresponding to Saturn's Hill radius.

Thermodynamic conditions inside the subnebula: Figure 1 and 2 represent the temperature and pressure conditions inside the subnebula, for different epochs of its evolution, as a function of the distance to Saturn. Note however that, during the beginning of phase 1 (before 0.2 Myr), the thickness of the subnebula is quite high, and the approximation of thin disk is inaccurate. The results at early epochs must then be taken with caution. However, it can be seen that the subnebula cools rapidly from a high temperature and pressure period to a cold and quiescent phase where ices can be preserved from vaporization.

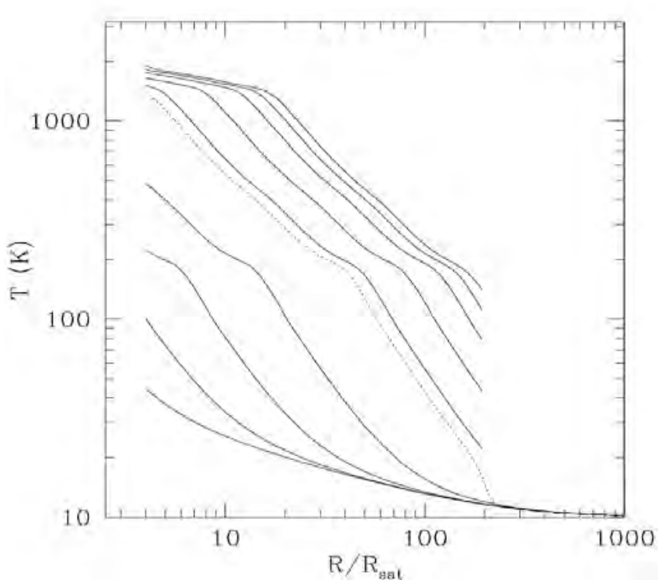

Figure 1: Temperature inside the subnebula, as a function of the distance to Saturn (in Saturn's radius). The solid lines are plotted, from top to bottom, after 0Myr (corresponding to the time when Saturn has accreted 70% of its final mass), 0.1 Myr, 0.2 Myr, 0.3 Myr, 0.35 Myr, 0.4 Myr, 0.5 Myr, 0.6 Myr and 0.7 Myr. The switch from phase 1 to phase 2 of the subnebula evolution occurs at 0.36 Myr. The dotted line gives the temperature 2000 years after the beginning of phase 2, and illustrates the very rapid evolution of the sub-

nebula during this stage. During phase 1 (first five curves), the outer radius of the subnebula is equal to 200 R_{Sat}.

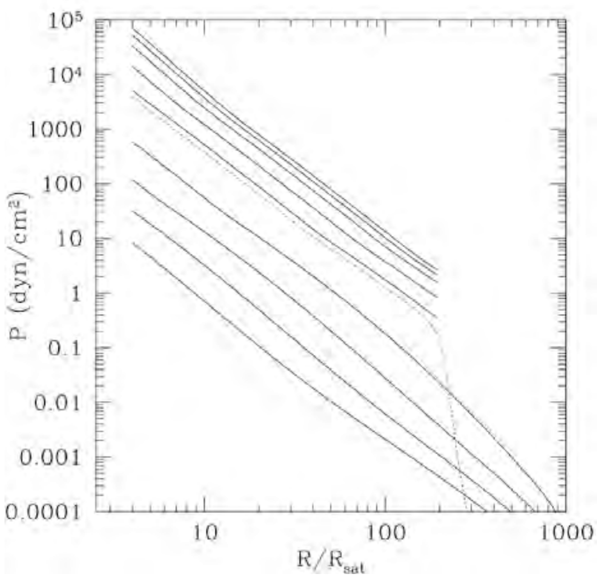

Figure 2: Same as Fig. 1, but for the pressure.

Implications for the origin of Titan: Similarly to the formation of the Galilean icy satellites in the Jovian subnebula [5] [6], Titan may have formed from satellitesimals produced either (1) in the solar nebula when the subnebula was cold enough to preserve from vaporization the ices incorporated in the migrating planetesimals or (2) in the cooling subnebula itself. The first case involves that ices incorporated in Titan share a composition similar to that of ices formed in the solar nebula [7]. In order to explain the current composition of Titan's atmosphere where noble gases other than argon (including primordial ^{36}Ar and radiogenic ^{40}Ar) were not detected [8], one must then assume that the amount of water in the feeding zone of Saturn was not sufficient to trap all the volatiles in the solar nebula gas-phase. It is then possible to allow the trapping of NH_3, CH_4, CO_2 under the form of hydrates and clathrate hydrates. Moreover, through this process, most of CO and noble gases should remain in the gas-phase. While this proposed mechanism remains compatible with the current atmospheric composition of Titan, it also requires that the composition of planetesimals accreted by Saturn is similar to that of Titan. This implies that Saturn's atmosphere should not contain noble gases such as xenon or krypton and that the composition of planetesimals accreted by the planet itself is different from that of planetesimals accreted by Jupiter. On the other hand, this statement is in conflict with current scenarios of giant planets formation that suggest that Jupiter and Saturn were formed in the same zone of the solar nebula from planetesimals sharing the same composition [2]. Since the enrichments in volatiles measured in Jupiter [9] require a high abundance of H_2O (i.e. an oversolar oxygen abundance) to trapp N_2 and CO in the solar nebula gas-phase [2], this appears incompatible with the current atmospheric composition of Titan if this latter is explained by invoking a strong depletion of H_2O in Saturn's feeding zone. We then favor an alternative scenario where Titan may be formed from satellitesimals that would have suffered a partial vaporization during their formation and/or migration in the Saturn's subnebula. The migration of satellitesimals in a balmy subnebula (as our model shows at intermediary epochs) could allow a partial or total vaporization of most volatile species (CO, N_2, Kr, Xe) whereas CH_4, CO_2, NH_3 would remain trapped in water ice. This scenario is the object of further developments.

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